

AN ARTICLE MADE OF A MAGNESIUM ALLOY TUBE

5

FIELD OF THE INVENTION

This invention relates to processes for extrusion of tubes from metal alloys
10 and structures formed by such processes, in particular to extrusion using
magnesium alloys.

BACKGROUND OF THE INVENTION

Metal profiles and tubes are often produced using extrusion. In the process, a
round metal block called a "*billet*" is introduced into a heated container, having a
15 ram at one end and a die at the other. The ram is used to apply a pressure on the
billet in the direction of the die. The billet is forced through an aperture in the die,
and the metal undergoes a deformation into an extruded body, having a cross-
section in the shape of the aperture. This is referred to as *direct extrusion*. In
another known method of extrusion, the die is moved toward the billet. The billet
20 therefore is stationary with respect to the container, eliminating friction there and
reducing the pressure needed for extrusion. However, surface defects on the billet
are propagated to the extruded material. This is referred to *indirect extrusion*.

The deformation of an object with one cross-sectional area into an object of
a smaller cross-sectional area results in an increase in length. The ratio of the cross-
25 sectional area of the billet to the cross-sectional area of the extruded body is
referred to in the art as well as in the present specification and claims, as the
extrusion reduction ratio.

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In order to create hollow shapes such as tubes using extrusion, a mandrel is placed inside the die aperture. The metal is forced to flow between the die and the mandrel, causing a hollow having the shape of the mandrel to be formed in the metal.

5 Recently, internal high pressure forming (IHPF) has been utilized to form parts having complex geometries, particularly in the automotive industry. IHPF utilizes fluid pressure to form the part into the desired shape of a mold. Using this process, components that would otherwise be manufactured as several pieces and then joined together can be manufactured as one. This reduces the mass of the component and maintains its stiffness, due to the elimination of spot-welded joints.

10 Other advantages of using IHPF include weight reduction through more efficient section design of the component and tailoring of its wall thickness, improved structural strength, lower tooling cost due to fewer parts, fewer secondary operations such as welding of sections, tighter dimensional tolerances, and fewer parts required for final assembly.

15 Presently, IHPF is used to manufacture steel and aluminium parts.

SUMMARY OF THE INVENTION

The present invention is directed toward adaptation of internal high pressure forming to magnesium, for use, in particular, in reducing a vehicle's weight and to thereby increase fuel economy and reduce emissions.

20 According to one aspect of the present invention, there is provided an article made of a magnesium alloy tube, the article having a grain size of between 10 μ m and 50 μ m and being manufactured by internal high pressure forming. The temperature of the internal high pressure forming is between 200°C and 605°C. The tube is manufactured by extrusion, wherein the extrusion temperature is 25 between 300°C and 605°C, the extrusion speed is substantially between 5 mm/sec and 45 mm/sec, and the extrusion reduction ratio is substantially between 10:1 and 50:1. The tube may be annealed for 6 hours at 300°C.

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According to another aspect of the present invention, there is provided a process for forming a hollow tube by extrusion of a billet made from a magnesium alloy, comprising the steps of heating the billet to a predetermined temperature within a temperature range, extruding the billet using an indirect
5 extrusion process, wherein the temperature is within a range of 300°C to 605°C, the extrusion speed is substantially in the range between 5 mm/sec and 45 mm/sec, and the extrusion reduction ratio is substantially in the range between 10:1 and 50:1.

According to a further aspect of the invention, there is provided a process
10 for internal high pressure forming using tubes obtained according to the above-described process. The process comprises the steps of cooling the tube in a predetermined temperature for a predetermined amount of time, sealing the tube from both ends, introducing a pressure medium into the tube, positioning the tube in a mold having a guiding zone and an expansion zone, wherein the temperature
15 of the expansion zone is between 200°C and 605°C, and applying an axial compression force on the tube, the result being that the portion of the tube that is within the expansion zone expands to fill the zone and adopt thereby its shape. The tube is then cooled for a predetermined period of time at a predetermined temperature.

20 BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, an embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 shows a partial cut-away view of a typical extrusion press which
25 may be used with an extrusion process of the present invention;

Fig. 2 is an illustration of a typical setup for a tooling which may be used in internal high pressure forming; and

Fig. 3 is an illustration the setup of Fig. 2, wherein a tube is undergoing internal high pressure forming.

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DETAILED DESCRIPTION OF THE INVENTION

An extrusion press, known in the art, is employed using specific parameters in order to form extruded magnesium parts with properties that enable plastic deformation to be accomplished thereon in industrial applications, such as in the automotive industry.

Fig. 1 illustrates an extrusion press **10** comprising a container **12** adapted to receive a magnesium billet **14**, a ram **16**, a die **18**, and a floating mandrel (not seen in Fig. 1). The die **18** comprises an aperture **19** of a predetermined shape. The magnesium billet **14** is heated so that its temperature is within a range of 300°C to 605°C. The heated billet **14** is positioned in the container **12**, and the die **18** is moved toward the billet **14**, exerting a pressure which forces the billet **14** to deform, becoming an extrusion **20** which has a circumference similar to the aperture **19**. The extrusion press **10** is adapted to maintain the billet **14** at the predetermined temperature during extrusion. The die **18** is moved at an extrusion rate substantially between 5 mm/sec and 45 mm/sec. The mandrel is positioned so that it forms a hollow **21** in the extrusion **20** and determines the size and shape of the hollow. The space between the die **18** and the mandrel determines the cross-sectional area of the extrusion **20**. The extrusion reduction ratio is substantially between 10:1 and 50:1.

When heating the magnesium billet **14**, it should be kept in mind that additional heating will occur due to the pressure inherent to the extrusion process. Therefore, the billet **14** should not initially be heated to the desired temperature, so that it is not exceeded during the extrusion.

The billet **14** used for the extrusion may be an undrilled billet, or a predrilled billet having a hollow center.

The magnesium used in this process may be any commercially available magnesium alloy, such as AM60, AS41, AZ31, AZ61, AZ80, AZ91, ZE41, or ZM21. Alternatively, it may be a custom-made alloy. Preferably, the magnesium used with the process of the present invention is either the AZ31 or ZM21 alloy.

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The combination of parameters for any given magnesium alloy may be determined by one skilled in the art by trial and error.

According to one particular embodiment, the chemical composition of the magnesium alloy used in the process according to the present invention is
5 2.856% Al, 1.022% Zn, 0.329% Mn, 0.004% Fe, 0.038% Si, 0.001% Cu, and 0.001% Ni. In one experiment performed, a continuous casting system was used with a flat die of 42 mm, a mandrel of 38 mm and a container of 110 mm. The magnesium billet was 155 mm in length, 107 mm in diameter and was predrilled with a hole diameter of 38 mm (need to confirm pre-drilled). The extrusion rate
10 was 1.6 mm/sec, with a billet and container heated to 320°C. The extrusion reduction ratio was about 30:1 with an overall force of 4.45 MN.

The magnesium tube obtained using the above-described process had mechanical properties which provide the strength and durability to withstand, without failure, plastic deformations inherent in further production involving the
15 tube. Specifically, it had a yield strength of 195 N/mm², an ultimate tensile strength (UTS) of 255 N/mm², and a 14% elongation at fracture.

One process for which the magnesium tube obtained as described above may be used is internal high pressure forming. With reference to Fig. 2, this is accomplished with the aid of a specialized tooling 22. The tooling 22 comprises a
20 clamping unit 25 disposed on each side of the tube 23 and a forming unit 27 surrounding it. The clamping unit 25 comprises crossheads 24, hydraulic cylinders 26, sealing punches 28, and appropriate heating and cooling means. The sealing punches 28 are adapted to seal the ends of the tube during forming, and at least one comprises an opening 42 adapted to introduce a pressure medium
25 from a pressure source (not shown) into the tube. The forming unit 27 comprises body material 30, dies 32 which form an expansion zone 36, inserts 34 which form guiding zones 38, and appropriate heating and cooling means.

Referring to Fig. 3, the tube 23 is deformed within the tooling 22. When the tube 23 is retained in the tooling, its ends are sealed, and a pressure medium
30 is introduced at a forming pressure therein through the opening 42. A high

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pressure is applied to the medium, and an axial compression force (indicated by arrows 44) is applied to the tube 23. The expansion zone 36 is maintained at a temperature, substantially in the range of 200°C to 605°C, to permit the necessary circumferential strain for forming. In the guiding zone 38 a lower
5 temperature is maintained, for example, in the range of 100°C to 200°C. This is to ensure that the flow stress of the portion of the tube 23 in the guiding zone 38 is sufficient to transfer the axial force to the portion of the tube in the expansion zone 36. (For example, depending on the alloy used, in the temperature range of about 350°C to 400°C, the flow stress can decrease to 40 N/mm². The higher the
10 axial force that is transferred to the portion of the tube in the expansion zone, the higher the circumferential strain that can be achieved, which leads to higher formability.) As a result, the tube 23 deforms in the expansion zone 36, and forms a bulge 40 which takes the shape of the die 32.

It will be appreciated to one skilled in the art that the forming pressure is
15 determined based on the magnesium alloy used to manufacture the tube, the thickness thereof, the specific geometry of the part to be formed, and the temperature used for forming. A smaller radius and a lower temperature require a higher forming pressure. In addition, a thicker wall requires a higher forming pressure.

20 The pressure medium is a fluid, being either a gas or a heat resistant fluid. According to one embodiment, it is a gas which does not react with any other material it will come in contact with during the course of IHPF. It is preferably recoverable for subsequent use. Specifically, nitrogen or one of the noble gasses is used. Using a gas has several advantages over using a liquid, in that gasses may be
25 heated to high temperatures as described with respect to the processes herein without undergoing decomposition.

The formability of the magnesium tube during IHPF is partially influenced by the strain rate of the material. This influence increases with higher temperatures. Depending on process time and necessary formability, the strain rate may vary
30 between $2 \times 10^{-1} \text{sec}^{-1}$ and $1 \times 10^{-4} \text{sec}^{-1}$.

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Previous heat treatment may also influence the initial structure of the magnesium tube. The tubes may be annealed at temperatures that are substantially between 200°C and 600°C. In one preferred case, the annealing temperature is between 250°C and 300°C. When annealed in this temperature range for a maximum of 6 hours, a uniform, fine-grained structure may be observed in the tube. A grain size between 10µm and 50µm can be realized. This fine-grained structure leads to an improved formability, especially at low strain rates (smaller than $2 \times 10^{-1} \text{sec}^{-1}$).

The process described herein, and more specifically, the steps which involve IHPF may additionally be followed by subsequent IHPF operations in order to further deform or provide additional structural modifications to the tube.

According to one example, the following conditions are used for IHPF. Subsequent to extrusion, the magnesium tube is annealed at 300°C for 6 hours. This annealing time leads to a uniform, fine-grained structure. One who is versed in the art will appreciate that a fine grain structure is particularly suitable for IHPF and similar processes. Thereafter, the magnesium tubes are preheated to a forming temperature of 350°C. The expansion zone is kept at a temperature of 350°C, and the guided zone is kept at a temperature of 250°C. At 350°C, the total elongation allowed is near a peak of about 35%. An axial force is applied by the hydraulic cylinders, which causes a compressive stress condition in the wall of the tube. As the pressure medium, nitrogen gas is used. The pressure vs. time path ensures a constant strain rate over the process time.